

THERMAL ANALYSIS OF HEAT EXCHANGER WITH THE HELP OF TAGUCHI METHOD

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ABSTRACT

Engineering are continually being asked to improve processes and increase efficiency. These request may arise as a result of the need to increase process throughout, increase profitability, or accommodate capital limitations. Processes which use heat transfer equipment must frequently be improved for these reason. This paper provide the application of Taguchi method in heat exchanger performance.

Key words: Heat Exchanger, Overall Heat Transfer Coefficient, Taguchi Method, Signal-To- Noise Ratio.

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1. INTRODUCTION

A heat exchanger is a device that transfers thermal energy from a high temperature fluid to a low-temperature fluid with both fluids moving through the device. Examples in practice in which flowing fluids exchange heat are air intercoolers and preheaters, condensers and boilers in steam plant, condensers and evaporators in refrigerator units, and many other industrial processes in which a liquid or gas is required to be either cooled or heated (Eckert and Drakes 1974). Heat exchangers are of basically three types

1.1. Transfer type

In which both fluids pass through the exchanger and heat gets transferred through the separating walls between the fluids.

1.2. Storage type

In this, firstly the hot fluid passes through a medium having high heat capacity and then cold fluid is passed through the medium to collect the heat. Thus hot and cold fluids are alternately passed through the medium.

1.3. Direct contact type

In this type, the fluids are not separated but they mix with each other and heat passes directly from one fluid to the other. Transfer type heat exchangers are the type most widely used. In transfer type heat exchangers, three types of flow arrangements are used, viz. parallel, counter or cross flow. In parallel flow, both the fluids flow in the same direction while in counter flow; they flow in the opposite direction. In cross flow, they flow at right angles to each other. The apparatus consists of two concentric tubes in which fluids pass. The hot fluid is hot water which is obtained from an electric geyser. Hot water flows through the inner tube, in one direction. Cold fluid is cold water which flows through the annulus. Control valves are provided so that direction of cold water can be kept parallel or opposite to that of hot water. Thus, the heat exchanger can be operated either as parallel or counter flow heat exchanger. The temperatures are measured with temperature indicator. Thus, the heat transfer rate, heat transfer coefficient, L.M.T.D. and effectiveness of heat exchanger can be calculated for both parallel and counter flow.

2. TAGUCHI METHOD

The method presented in this study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage. Although similar to design of experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore reducing costs and increasing profit.

The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. The parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analysing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters.

Taguchi method the experimental procedure included experimental design by Taguchi method, welding materials, welding equipment and welding procedure. Taguchi method can study data with minimum experimental runs. In this paper, the design of experiment work can be decided by this method.

Steps of Taguchi method are as follows:

1. Identification of main function, side effects and failure mode.
2. Identification of noise factor, testing condition and quality characteristics.
3. Identification of the main function to be optimized.
4. Identification the control factor and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analysing the data, prediction of the optimum level and performance.
8. Performing the verification experiment and planning the future action.

3. DESIGN OF EXPERIMENTS

3.1. SPECIFICATIONS

- Heat exchanger - a) Inner tube - Φ 12.7 mm O.D., Φ 11.0 mm I.D. copper tube.
- b) Outer tube - Φ 28 mm NB G.I. pipe.
- c) Length of heat exchanger is - 1.6 m.
- Electric heater - 3 kw capacity to supply hot water.
- Valves for flow and direction control - 5 Nos.
- Temperature Indicator to measure temperatures - 10 to 110 $^{\circ}\text{C}$ - 6 Nos.
- 5) Measuring flask and stop clock for flow measurement.

3.2. The Overall Heat Transfer Coefficient

A heat exchanger typically involves two flowing fluids separated by a solid wall. Heat is first transferred from the hot fluid to the wall by convection through the wall by conduction and from the wall to the cold fluid again by convection. Any radiation effects are usually included in the convection heat transfer coefficients (Holman 2002).

3.3. Analysis of Heat Exchangers

Logarithmic Mean Temperature Difference The method used in the analysis of the heat exchanger in this research work is the Logarithmic Mean Temperature Difference (LMTD), and it is defined as that temperature difference which, if constant, would give the same rate of heat transfer as actually occurs under variable conditions of temperature difference. In order to derive expression for LMTD, the following assumptions were made: The overall heat transfer coefficient U is constant, the flow conditions are steady, the specific heats and mass flow rates of both fluids are constant, there is no loss of heat to the surroundings, there is no change phase either of the fluid during the heat transfer, the change in potential and kinetic energies are negligible, axial conduction along the tubes of the heat exchanger is negligible (Saunders 1981).

3.4. Development of Design Matrix

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. For example, a Three -level

process parameter counts for three degrees of freedom. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for the two process parameters. In the present study, the interaction between the heat exchanger parameters is neglected. Once the degrees of freedom required are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study, an L09ss orthogonal array was used. The input heat exchanger process parameters considered for this research work inlet temperature, outlet temperature, mass flow rate. The output quality characteristic was overall heat transfer coefficient. All these parameters were investigated on 3 levels. The heat exchanger input variables and their limits are given Table 3. For avoiding systematic errors further in carrying out the experiments, 09 experiments were randomized for placing. The experimental layout for the heat exchanger process parameters using L09 orthogonal array and the experimental results for the overall heat transfer are calculated.

Variable	Notation	Level			Units
		1	2	3	
Cold fluid Temperature	t_c	23.5	23.5	23.5	$^{\circ}\text{C}$
Hot fluid Temperature	t_h	22.8	24	26	$^{\circ}\text{C}$
Time	t	40.72	40.11	39.69	Sec.

3.5. Analysis of experimental results based on taguchi method analysis of s/n ratio

According to Taguchi method, S/N ratio is the ratio of “Signal” representing desirable value, i.e. mean of output characteristics and the “noise” representing the undesirable value i.e., squared deviation of the output characteristics. It is denoted by η and the unit is dB. The S/N ratio is used to measure quality characteristic and it is also used to measure significant heat transfer parameters.

According to quality engineering the characteristics are classified as Higher the best (HB) and lower the best (LB). HB includes overall heat transfer rate which desires higher values. Similarly LB includes LMTD for which lower value is preferred.

The summary statistics Higher the best performance 09 the best performance

$$L_{ij} = \frac{1}{n} \sum \frac{1}{y_{ijk}^2}$$

$$n_j = -10 \log (L_{ij})$$

3.6. Analysis of variance (ANOVA)

The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis, the sum of squares and variance are calculated. F-test value at 95 % confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated. The ANOVA analysis for percentage calibration.

4. CONCLUSION

This paper has presented an investigation on the optimization and the effect of heat exchanger parameters. The level of importance of the heat exchanger parameters on the overall heat transfer is determined by using ANOVA. Based on the ANOVA method, the highly effective parameters on overall heat transfer were found as inlet temperature and LMTD, whereas outlet temperature was less effective factors. An optimum parameter combination for the maximum heat transfer was obtained by using the analysis of S/N ratio.

Type of Flow	Hot Water			Cold Water		
	Temperatures		Time For 1 Litre Water	Temperatures		Time For 1lit.Water
	IN °C	OUT °C	Xh Sec	IN °C	OUT °C	Xc Sec
Parallel Flow	44	38.5	41.81	23.5	26	16.41
Counter Flow	40.5	35.5	35.22	23	26	19.94

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